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Effect of organic and mineral fertilizers on N-use by wheat under different irrigation frequencies

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Abstract

A field trial was established in Errachidia, southern Morocco, to investigate the interaction between wheat residue management and mineral ^{15}N-labelled ammonium sulphate, under different irrigation treatments, applied to wheat (*Triticum durum* var. Karim). In treatments I1, I2, I3 and I4, plots were irrigated every 10, 15, 21 and 30 days. Each plot contained three sub-plots that received three fertilization treatments: T1 received 42 kg N ha^{-1} of ammonium sulphate before seedling, 42 kg N ha^{-1} of ammonium sulphate labelled with 9.764 at% ^{15}N excess at tillering and 84 N kg ha^{-1} of ammonium sulphate at flowering; T2 received 42 kg N ha^{-1} of ammonium sulphate labelled with 9.764 at% ^{15}N excess at seedling, 42 kg N ha^{-1} at tillering and 42 kg N ha^{-1} at flowering; T3 received 4800 kg ha^{-1} of wheat residue labelled with 1.504 at% ^{15}N excess and 42 kg N ha^{-1} of ammonium sulphate before seedling and 42 kg N ha^{-1} of ammonium sulphate at flowering. Nitrogen fertilization with 168 kg N ha^{-1} did no significantly increase grain and straw yields in comparison to the 126 kg N ha^{-1} application. The combination of the organic input and supplementary application of mineral fertilizer N has been found as a more attractive management option. For all irrigation treatments, the % recovery of N in the whole plant was higher in plants that received ^{15}N at tillering (63%, 49% respectively for irrigation intervals between 10 and 30 d) than in plants that received ^{15}N just after seeding (28% for irrigation each 10- and 30-d intervals). For the irrigation treatment each 10 and 15 days, the ^{15}N was mainly recovered by the grain for all fertilization treatments, whereas for irrigation treatment each 30 days, the grain and straw recovered nearly equal amounts of fertilizer. For grain and straw of wheat, nitrogen in the plant derived from the fertilizer was low, while most of the N was derived from the soil for all irrigation and fertilization treatments. The % nitrogen in the plant derived from the fertilizer values showed no significant difference between the different plant parts. The results suggested a dominant influence of moisture availability on the fertilizer N uptake by wheat. Under dry conditions the losses of N can be allotted to denitrification and volatilisation. ***To cite this article: L.L. Ichir et al., C. R. Biologies 326 (2003).***

Résumé

Effets de l'apport des résidus de blé et de l'azote minéral sur la culture de blé sous différentes fréquences d'irrigation. Un essai au champ est installé dans la région d'Errachidia, au sud du Maroc. Il a comme objectif d'évaluer les effets de l'enfouissement de résidus de blé combinés aux engrais minéraux azotés, sous différents traitements d'irrigation, sur le blé dur

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(*Triticum durum*, var. Karim). Dans les traitements I1, I2, I3 et I4, les parcelles sont irriguées tous les 10, 15, 21 et 30 jours. Chaque parcelle principale a été subdivisée en trois parcelles élémentaires, qui ont reçu trois traitements de fertilisations : T1 a reçu 42 kg N ha^{-1} de sulfate d'ammonium avant le semis, 42 kg N ha^{-1} de sulfate d'ammonium enrichi avec 9,764% en excès de ^{15}N au stade tallage et 84 kg N ha^{-1} de $(NH_4)_2SO_4$ au stade floraison ; T2 a reçu 42 kg N ha^{-1} de sulfate d'ammonium enrichi avec 9,764% en excès de ^{15}N au stade semis, 42 kg N ha^{-1} de sulfate d'ammonium au stade tallage et 42 kg N ha^{-1} de $(NH_4)_2SO_4$ au stade floraison ; T3 a reçu 4800 kg ha^{-1} de résidus de blé enrichis en ^{15}N à 1,504% en excès et 42 kg N ha^{-1} de $(NH_4)_2SO_4$ avant le semis et la même dose à la floraison. L'apport de 168 kg N ha^{-1} n'a pas d'effet significatif sur le rendement en grain et en paille en comparaison d'un apport de 126 kg N ha^{-1}. L'application des résidus mélangés avec les engrais inorganiques en quantités faibles pourrait diminuer l'utilisation des engrais chimiques. Pour toutes les irrigations, le coefficient réel d'utilisation d'azote par la plante entière est plus élevé pour les plantes qui ont reçu ^{15}N au stade tallage (63% et 49% pour les intervalles d'irrigation de 10 et 30 jours) que pour les plantes recevant l'azote marqué juste après la levée (28% pour les irrigations tous les 10 et 30 jours). Pour le traitement d'irrigation tous les 10 et 15 jours, l'azote marqué est principalement récupéré par les grains pour tous les traitements de fertilisation, tandis que, pour l'irrigation tous les 30 jours, les grains et la paille ont récupéré des quantités d'azote presque égales. Pour les graines et de la paille, l'azote dans la plante dérivée du fertilisant est faible, tandis que davantage d'azote est dérivé à partir du sol pour tous les traitements d'irrigation et de fertilisation. Les valeurs du pourcentage d'azote dans la plante dérivée du fertilisant n'ont pas montré de différences significatives entre les différentes parties de la plante. Les résultats ont suggéré une influence importante de la disponibilité de l'humidité du sol sur l'absorption de fertilisant azoté par le blé. L'azote non récupéré pourrait être, soit retrouvé dans l'azote résiduel dans le sol et dans les racines non récoltées, soit lessivé hors du profil ou dénitrifié. ***Pour citer cet article : L.L. Ichir et al., C. R. Biologies 326 (2003).***

Keywords: irrigation frequency; ^{15}N-labelled fertilizer; wheat residues; % ^{15}N recovery

Mots-clés : fréquence d'irrigation ; engrais enrichi en ^{15}N ; résidus de blé ; % recouvrement de ^{15}N

Version française abrégée

Ce travail a été mené au champ dans la région d'Errachidia, dans le Sud du Maroc. Il a comme objectif d'évaluer les effets de l'enfouissement de résidus de blé combinés aux engrais minéraux azotés, sous différents traitements d'irrigation, sur le blé dur (*Triticum durum*, var. Karim). Dans les traitements I1, I2, I3 et I4, les parcelles sont irriguées tous les 10, 15, 21 et 30 jours, respectivement. Chaque parcelle principale a été subdivisée en trois parcelles élémentaires, qui ont reçu trois traitements de fertilisation : T1 a reçu 42 kg N ha^{-1} de sulfate d'ammonium avant le semis, 42 kg N ha^{-1} de sulfate d'ammonium enrichi avec 9,764% en excès de ^{15}N au stade tallage et 84 kg N ha^{-1} de $(NH_4)_2SO_4$ au stade floraison, T2 a reçu 42 kg N ha^{-1} de sulfate d'ammonium enrichi avec 9,764% en excès de ^{15}N au stade semis, 42 kg N ha^{-1} de sulfate d'ammonium au stade tallage et 42 kg N ha^{-1} de $(NH_4)_2SO_4$ au stade floraison, tandis que T3 a reçu 4800 kg ha^{-1} de résidus de blé enrichis en ^{15}N à 1,504% en excès et 42 kg N ha^{-1} de $(NH_4)_2SO_4$ avant le semis et la même dose à la floraison. Dans ces conditions expérimentales, sous des conditions favorables d'humidité (10, 15 et 21 jours), l'incorporation de la paille de blé plus 84 kg N ha^{-1} exerce un effet sur le rendement en blé similaire à celui de l'apport de 126 ou 168 kg N ha^{-1}. L'application des résidus mélangés avec les engrais inorganiques en faibles quantités pourrait diminuer l'utilisation des engrais chimiques. Dans l'ordre d'utilisation efficiente de l'eau, il est recommandé d'irriguer le blé à un intervalle de 15 à 21 jours. Lorsque les conditions d'humidité ne sont pas limitantes, l'azote dans la plante a été distribué comme suit : environ 2/3 dans la graine et 1/3 dans la paille ; seulement environ 4% ont été situés dans les racines récoltées. La majeure partie de l'azote a été dérivée du sol pour tous les traitements d'irrigation et de fertilisation. On observe des différences significatives pour ce qui concerne le recouvrement de l'azote, selon qu'il est appliqué à différentes périodes de croissance de blé. Pour I1, le pourcentage de recouvrement de l'azote a été de 63% lorsque l'azote a été appliqué au stade tallage et de 28% pour le traite-

ment recevant l'azote au stade plantule. Dans I4, le % de recouvrement de l'azote a été de 49% et 28% pour le T1 et le T2, respectivement. Pour le traitement avec l'apport des résidus enrichis en ^{15}N, le recouvrement de l'azote a été de 8% pour I1 et 5% pour I4. L'azote non récupéré pourrait être, soit trouvé dans l'azote résiduel dans le sol et dans les racines non récoltées, soit lessivé hors du profil ou dénitrifié.

1. Introduction

The Errachidia area in southern Morocco has a Saharan Mediterranean climate [1]. Consequently, the agriculture is based on irrigation practices. Farmer lands are restricted along the rivers. Consequently, agriculture is very intensive, with application of increasing quantities of inorganic fertilizers. Dry-matter production is mainly limited by the available soil water. Consequently, efficient use of the available water is very important [2,3]. In this area, wheat is a major crop [4]. The rate of mineral N fertilizer applied to wheat by farmers is 170 $kg\,N\,ha^{-1}$. Water and interaction affecting residue decomposition and N dynamics should be considered in management strategies for soil protection and nutrient cycling [5]. Soil moisture is the factor that substantially affects N mineralisation. Increasing soil moisture generally increases soil organic matter decomposition within the ranges typical of most soils [6]. The application of organic matter was reported to help conserving soil moisture [7,8].

Organic inputs are always recommended as alternatives to the mineral fertilizers in Africa. Rather than chemical fertilizers, organic amendments have been suggested as a method for 'low input agriculture' to achieve sustainability in dry land agriculture [9]. Several low input techniques to regenerate soil fertility are based on the incorporation of organic matter into the soil. Research has been conducted to study the nutrient supply capacity of various organic materials available in a particular location. With regard to N, field studies showed that the total N recovery from organic residues in the first crop is very variable, but less than 20% [10, 11]. The combination of the organic input and supplementary application of mineral fertilizer N has been proposed as a more attractive management option to solve problems of N deficiency in soil [12,13].

Numerous factors are reported to affect the decomposition rates of organic residues. Climatic conditions and especially soil moisture play an important role [14,15]. The decomposition of the residues requires adequate water content for microbial activity as well as the diffusion of the nutrient elements released during the decomposition process [16]. In a dry soil, N mineralisation is reduced [16] and nitrification can cease [12]. Optimal moisture for the decomposition of plant residues and further transformations is in the range between 60 and 100% of field capacity [17]. Cycles of drying and wetting stimulate the activity of the microorganisms and the mineralisation of N is favoured [18,19]. Similarly, Badaruddin et al. [20] showed that straw decomposition in the soil was more important under increased soil moisture. None of theses studies evaluated crop decomposing under irrigated field conditions or in an environment similar to that of southern Morocco.

Our aim was to evaluate the effects of the application of mineral fertilizers and wheat straw on the N uptake and yield of wheat under irrigation treatments. The relative contribution of fertilizer N was estimated using ^{15}N isotope techniques.

2. Materials and methods

2.1. Site description

The experiment was conducted at the Experimental Farm of Tafilalet (SEMVAT) in southern Morocco. In 1997–1998, the annual rainfall averaged 123 mm at the experimental site. The mean annual temperature was 18 °C, with a minimum of 8 °C (January) and maximum of 30 °C (July). The soil of the experimental fields had a clay loamy texture with 29.4% clay, 34.1% loam, 36.5% sand, a bulk density of 1.3479 $kg\,l^{-1}$, a porosity of 49.2%, a field capacity of 27% and a permanent wilting point of 12%. The soil contained 0.06% total N, 0.88% organic matter and a pH of 8.5 (H_2O) in the 0–20-cm horizon.

2.2. Experimental details

Plots of 3 × 3 m were delimited. Before sowing, triple super phosphate was applied at a rate of 124 $kg\,N\,ha^{-1}$ and potassium sulphate at a rate of 84 $kg\,N\,ha^{-1}$. The plots were seeded with wheat (*Triticum durum* var. Karim) at the rate of 160 $kg\,ha^{-1}$ on 22 December 1997. Seeding depth was 3 cm. The plants were thinned to have 20 cm between them.

The experimental design was a split-plot, replicated three times. The main plot treatment consisted of four frequency irrigations: I1 plots were irrigated every 10 days; I2 plots were irrigated every two weeks; I3 plots were irrigated every three weeks; I4 plots were irrigated every four weeks. Each dose of irrigation was 70 mm. Each plot contained three sub-plots which received three fertilization treatments: T1 ($42\,N + 42\,^{15}N + 84\,N$): received 42 $kg\,N\,ha^{-1}$ of ammonium sulphate before seedling, 42 $kg\,N\,ha^{-1}$ of ammonium sulphate enriched with 9.764% ^{15}N excess at tillering and 84 $kg\,N\,ha^{-1}$ ammonium sulphate at flowering; T2 ($42\,^{15}N + 42\,N + 42\,N$): received 42 $kg\,N\,ha^{-1}$ of ammonium sulphate labelled with 9.764 at% ^{15}N excess at seedling, 42 $kg\,N\,ha^{-1}$ at tillering and 42 $kg\,N\,ha^{-1}$ at flowering; T3 ($^{15}R + 42\,N + 42\,N$): received 4800 $kg\,ha^{-1}$ of wheat residue labelled with 1.504 at% ^{15}N excess (^{15}R) and 42 $kg\,N\,ha^{-1}$ of ammonium sulphate before seedling and 42 $kg\,N\,ha^{-1}$ ammonium sulphate at flowering.

2.3. Plant analysis and calculations

The plots were harvested on 3 June 1998. The grain was separated from the rest of the plant. The samples were oven dried at 75 °C for 48 h and then weighed. Plant material (straw, grain and roots) was analysed for total nitrogen and ^{15}N excess using an automatic N analyser coupled to a SIRA 9 (ANA-SIRA) mass spectrometer [21]. The percentage of ^{15}N recovered from the fertilizer in the plant samples was calculated according to Zapata [22]:

$$^{15}\text{N recovery from the fertilizer} = N_{sample}(c-b)/R(a-b)$$

where N_{sample} ($kg\,N\,ha^{-1}$) is the total N content of the sample; a (%) the ^{15}N abundance of the applied fertilizer, b (%) the ^{15}N abundance of an untreated sample (background value) and c (%) the ^{15}N abundance of the treated sample. R ($kg\,N\,ha^{-1}$) is the rate of the applied fertilizer. The percentage of N in the plant derived from the fertilizer ($\%N_{dff}$) is calculated using the following formula:

$$\%N_{dff} = 100 \times (c-b)/(a-c)$$

The percentage of N in the plant derived from the soil and more generally from the unlabelled source of nutrient ($\%N_{dfs}$) is the difference:

$$\%N_{dfs} = 100 - \%N_{dff}$$

Data were statistically analysed with SPSS (Statistical Package for Social Sciences). Differences between treatments were analysed using ANOVA, followed by least significant difference (LSD) at the 0.05 probability level and T test.

3. Results and discussion

3.1. Dry matter yield and total N

For all irrigation treatments, the N fertilization with 168 $kg\,N\,ha^{-1}$ was not significantly different from the fertilization with 126 $kg\,N\,ha^{-1}$. For the three irrigation treatments, I1, I2, I3, the results showed that wheat residues plus 84 $kg\,N\,ha^{-1}$ had similar effects on wheat yield than application of 168 $kg\,N\,ha^{-1}$ and 126 $kg\,N\,ha^{-1}$ (Table 1). Similar results were found by Vanlauwe et al. [11] with maize, who showed a 50% economy of fertilizer by combining residues with mineral fertilizer in southern Benin. The total N in the grains followed a similar trend as the dry matter content (Table 2).

For treatment I4, a significant difference ($P < 0.05$) was found between the grain yield of the treatment with residues (T3) and without residues (T1). Similarly, Purvis [23] indicated that straw incorporation inhibit wheat growth. This inhibition depended on the quantity and the distribution of rain during the year. According to the author, the depressive effect of residues of crops disappears with increase of humidity. Similarly, Badaruddin et al. [20] showed that straw decomposition was more important under increased soil moisture. The production of dry matter decreased with a lower irrigation frequency. This decrease was significant ($P < 0.05$) between I1 and I4 (Table 1). The interactive effect between irrigation treatments and fertilization was not significant for the straw and grain yield.

Table 1
Dry matter yield (kg ha^{-1}) of wheat as affected by fertilization and irrigation treatments

Treatments	I1 (10d)	I2 (15d)	I3 (21d)	I4 (30d)	[b]$LSD_{0.05}$
			Grain		
T1 (42 N + 42 ^{15}N + 84 N)	4390	4050	2374	1960	1012.30
T2 (42 ^{15}N + 42 N + 42 N)	3118	2644	1735	1675	550.38
T3 (^{15}R + 42 N + 42 N)	2808	2634	2660	984	830.50
[a]$LSD_{0.05}$	NS	NS	NS	638	
			Straw		
T1 (42 N + 42 ^{15}N + 84 N)	8650	6883	6001	5666	1867.4
T2 (42 ^{15}N + 42 N + 42 N)	7929	5494	5274	4728	2503.7
T3 (^{15}R + 42 N + 42 N)	5720	5741	4300	3284	1357.7
[a]$LSD_{0.05}$	NS	NS	NS	NS	

^{15}N: Labelled nitrogen, ^{15}R: labelled residue, $LSD_{0.05}$: significant difference.
[a] Between fertilization treatments; [b] between irrigation treatments at 5% level.

Table 2
N uptake (kg ha^{-1}) by wheat as affected by fertilization and irrigation treatments

Treatments	I1 (10d)	I2 (15d)	I3 (21d)	I4 (30d)	[b]$LSD_{0.05}$
			Grain		
T1 (42 N + 42 ^{15}N + 84 N)	141	142	74	62	57.3
T2 (42 ^{15}N + 42 N + 42 N)	74	75	75	48	24.6
T3 (^{15}R + 42 N + 42 N)	60	58	55	30	22.4
[a]$LSD_{0.05}$	65.79	55.84	NS	21.61	
			Straw		
T1 (42 N + 42 ^{15}N + 84 N)	61	62	46	46	NS
T2 (42 ^{15}N + 42 N + 42 N)	38	38	37	43	NS
T3 (^{15}R + 42 N + 42 N)	35	31	21	24	NS
[a]$LSD_{0.05}$	NS	NS	NS	21.95	
			Roots		
T1 (42 N + 42 ^{15}N + 84 N)	1.0	1.2	1.1	1.4	NS
T2 (42 ^{15}N + 42 N + 42 N)	4.8	4.5	3.6	4.6	NS
T3 (^{15}R + 42 N + 42 N)	0.7	0.8	1.2	8.0	3.6
[a]$LSD_{0.05}$	1.42	1.27	2.13	1.62	

$LSD_{0.05}$: Significant difference.
[a] Between fertilization treatments; [b] between irrigation treatments at 5% level.

For I1, I2, and I3, the plant N is distributed for about 2/3 in the grain and 1/3 in the straw; only about 4% is situated in the harvested roots. The same results were found by Van Cleemput et al. [24] on winter wheat, and on sunflower plants by Atta et Van Cleemput [25] and Corbeels et al. [3]. But, under water-stress conditions, N has a distribution of about 1/2 in the grain and 1/2 in the straw for all treatments. Nitrogen in the roots was higher (13% for treatment with residues). Under these conditions, no percolating moisture may prevent that the applied N is translocated to the root. Similar results were found by Corbeels [26].

3.2. Fertilizer-derived nitrogen and soil-derived nitrogen

The N recovered by the plant is derived from both the soil and the fertilizer. With the use of ^{15}N labelled fertilizer, the amount of N derived from the fertilizer (N_{dff}) and the amount of N derived from the soil (N_{dfs}) were determined (Table 3).

Table 3
Nitrogen in the different plant parts derived from labelled fertilizer (%N_{dff}) at harvest (LSD at 5%)

Treatments	I1 (10d)	I2 (15d)	I3 (21d)	I4 (30d)
	Grain			
T1 (42 N + 42 ^{15}N + 84 N)	12.57	14.14	14.80	18.52
T2 (42 ^{15}N + 42 N + 42 N)	9.86	9.20	6.40	9.84
T3 (^{15}R + 42 N + 42 N)	6.34	9.16	10.56	6.98
[a]$LSD_{0.05}$	3.00	2.56	3.15	5.60
	Straw			
T1 (42 N + 42 ^{15}N + 84 N)	14.94	19.12	15.76	20.04
T2 (42 ^{15}N + 42 N + 42 N)	10.22	7.79	9.79	15.84
T3 (^{15}R + 42 N + 42 N)	7.65	9.98	10.85	7.80
[a]$LSD_{0.05}$	5.70	7.08	4.37	1.30
	Roots			
T1 (42 N + 42 ^{15}N + 84 N)	13.91	12.89	15.07	16.52
T2 (42 ^{15}N + 42 N + 42 N)	12.89	12.92	13.86	17.87
T3 (^{15}R + 42 N + 42 N)	9.51	10.50	10.99	11.55
[a]$LSD_{0.05}$	4.55	NS	1.19	5.52

$LSD_{0.05}$: significant difference.

[a] Between fertilization treatments.

For grain and straw of wheat, N_{dff} were low while most of the N was derived from the soil for all irrigation and fertilization treatments. Corbeels et al. [27] also reported that soil N was more important than fertiliser N in wheat N uptake.

The proportion of N derived from ^{15}N-labelled fertilizer (N_{dff}) in grain and straw were significantly affected ($P < 0.05$) by N application time (Table 3). More N in the plant was derived from fertilizer when applied late in the growing season than applied early in the season. With optimal moisture conditions, the percentage of N in the plant derived from the labelled fertilizer applied at tillering was about 41%, at seeding it was 33% and, for the labelled residues, it was 24%. Probably the early-season application of N fertilizer could also have allowed more time for substitution and resulted in greater isotopic dilution with soil N, which would decrease the N_{dff} values [27]. The microbial needs could already be satisfied with native mineral soil N and fertilizer N applied at seeding, so that fertilizer N applied at tillering could remain more available to plant [28,29].

The %N_{dff} values showed no significant ($P > 0.05$) difference between the different plant parts. Similar results were observed by Corbeels et al. [27]. In contrast with these results, other investigators observed significant differences in %N_{dff} values for the different plant parts, especially for late N dressings. Grain may contain a greater proportion of the fertilizer N than the non-grain plant components, when applied to heading and flowering [30,31].

3.3. *Plant recovery of fertilizer N*

There was a significant difference ($P < 0.05$) in recovery of fertilizer N at different times of application. For I1, the %N recovery was 63% when the fertilizer N was applied at tillering and 28% for the treatment receiving fertilizers at seedling (Table 4). In I4, the % recovery was 49 and 28% for T1 and T2, respectively. The proportion of fertilizer N applied to seeding was probably more subjected to N loss prior to plant absorption. Root development at tillering stage could enable more efficient N absorption from fertilizer applied at this time. Similarly, Tran and Tremblay [32] showed that the maximum proportion of N fertilizer recovered by wheat was higher for the application at booting (62.1 to 68.4%) than for the application at seeding (37.8 to 45.7%). Hamid and Ahmad [33] found that the amount of N fertilizer used by wheat was lower for application at seedling (33.6%) than at tillering stage (51.5%).

Table 4
^{15}N recovery (%) in the different plant parts (LSD at 5%)

Treatments	I1 (10d)	I2 (15d)	I3 (21d)	I4 (30d)	$^{b}LSD_{0.05}$
			Grain		
T1 (42 N + 42 ^{15}N + 84 N)	41.25	47.01	22.64	26.76	13.24
T2 (42 ^{15}N + 42 N + 42 N)	17.26	16.00	11.84	11.31	NS
T3 (^{15}R + 42 N + 42 N)	4.83	5.99	4.45	2.55	NS
$^{a}LSD_{0.05}$	14.94	8.42	5.39	9.40	
			Straw		
T1 (42 N + 42 ^{15}N + 84 N)	21.77	28.05	16.89	21.77	NS
T2 (42 ^{15}N + 42 N + 42 N)	9.42	8.87	9.51	16.17	NS
T3 (^{15}R + 42 N + 42 N)	3.44	3.03	2.57	2.31	NS
$^{a}LSD_{0.05}$	7.80	5.02	3.13	7.00	
			Roots		
T1 (42 N + 42 ^{15}N + 84 N)	0.33	0.39	0.38	0.54	NS
T2 (42 ^{15}N + 42 N + 42 N)	1.45	0.61	0.56	0.39	0.24
T3 (^{15}R + 42 N + 42 N)	0.09	0.37	0.42	0.47	0.14
$^{a}LSD_{0.05}$	0.62	NS	NS	NS	

$LSD_{0.05}$: Significant difference.
[a] Between fertilization treatments; [b] between irrigation treatments at 5% level.

For the treatment with labelled residues and mineral fertilizer, the recovery in the plant was 8% for I1 and 5% for I4.

For I1, the labelled fertilizer was mainly recovered by the grain with all fertilization treatments, followed by the straw, while only a minor part of fertilizer N was recovered in the harvested roots (between 1 and 5%). These low ^{15}N recoveries in roots were also reported by others [26,33,34]. For an irrigation scheme of 30-d periodicity, the grain and straw recovered nearly equal amounts of fertilizer, although the amount in the roots was generally low.

For I1, I2, and I3, the amount of labelled N in the grain and straw was significantly higher when labelled ammonium sulphate was added at tillering than when ^{15}N was applied at seedling. This can be explained by some N loss. Thus, on irrigated surfaces, the efficiency of the fertilizer N by the plant depends on the duration of the N application. This result is similar to the findings of Van Cleemput and Hera [35]. The data on uptake of the applied labelled N show that the total amount of ^{15}N taken by the plant significantly differed depending on whether the treatment was made with or without residues, for all irrigation frequencies.

The results suggested that the $\%N_{dff}$ increased when the percent of recovery decreased. It means that in situation of water stress, roots take the N they need more in the fertilizer than in the soil reserve in comparison with the case of no water stress. In fact, the concentration of N in the soil solution is higher near the fertilizer than in the mean soil.

The non-recovered fertilizer N could be found either as residual N in the soil plus non-harvested roots, or leached out of the profile or denitrified [35, 36]. In this context, the fact that the 0–15 cm soil layer in our experiment was dried and re-wetted might have enhanced the denitrification potential [37].

4. Conclusion

Under the experimental conditions, with favourable moisture conditions (I1, I2 and I3), straw incorporation at 84 $kg\,N\,ha^{-1}$ had a similar effect on wheat yield than adding 126 or 184 $kg\,N\,ha^{-1}$. Application of residues together with inorganic nutrients by consequence decreased the use of chemical fertilizers. The application of ammonium sulphate at the tillering stage increased the efficiency of fertilizer N and improved its transfer to grain compared with the N applied at seedling. In order not to waste water, it was necessary to irrigate with intervals between irrigation, ranging between 15 at 21 days, because it increases the chance for the fertilizer to be leached into the subsoil where it can be taken up by the active roots. For the irrigation each 30 days, the fertilizer N in topsoil may be unavailable for plants. Occasional N losses during the growing season are supposed to be related to denitrification. Leaching losses were unlikely to occur. The nitrogen recovery obtained by the isotopic method can be assumed to be the most valid one.

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